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TRIM Timber Projections: An Evaluation Based on Forest Inventory Measurements

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Abstract

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Two consecutive timberland inventories collected from permanent plots in the natural pine type in North Carolina were used to evaluate the timber resource inventory model (TRIM). This study compares model predictions with field measurements and examines the effect of inventory data aggregation on the accuracy of projections. Projections were repeated for two geographic areas with two data aggregation schemes. The sensitivity of the model to harvest was tested with historical and adjusted values. For each simulation, the TRIM growth projection mechanism was tested with two types of yield tables. Yield tables developed from growth data produced projections that were closer to the measured inventory than did yield tables derived from volume data. This study suggests that timber growth measurements should be incorporated into TRIM yield tables when stands have the characteristics found in natural pine in North Carolina. The TRIM system is outlined, and the methods used to derive yield tables are discussed.

Keywords: Yield-table projection, growth simulation, growth measurements, inventory data aggregation, inventory models, forest survey, regional timber supply studies, model validation, South.

Research Summary

Regional timber studies requiring policy analysis and long-range planning often rely on models to predict the future demand and supply of timber resources. Predictions of the future are not useful, however, if the model user has little confidence in the models. This attempt to validate the timber resource inventory model (TRIM) was done to address concerns analysts expressed about growth projections that were below expectations.

The timber resource inventory model projects acres by user-defined strata for periods consistent with the age-class structure of the inventory. This model uses yield tables of net volume per acre by age class as growth guide curves to predict timber inventory volume. Adjustments to these yield tables can alter the results of regional timber supply predictions. For this study, two types of yield tables were developed to examine the TRIM growth mechanism and to evaluate inventory projections, fully stocked empirical yield tables and growth yield tables. The empirical yield tables were developed from inventory volume data, and the growth yield tables were developed from inventory growth data collected from remeasured sample plots.

All projection parameters were derived from two consecutive (and consistent) sets of data collected from forest survey plots that were measured about 10 years apart. The study objective was to use all available data to develop model inputs and then to compare outputs with the second set of inventory measurements. Evaluations of projected inventory, volume, and growth were based on their differences from the field-derived data. Inventory acres were aggregated two ways to check for bias that might be introduced when site classes were combined. One method of aggregation recognized three site productivity classes; the other combined all sites.

The results indicate that projections of growth are more sensitive to adjustments of the yield table than to either inventory aggregation by site class or to the level of harvest. The projections made from the growth yield tables were closer to the measured inventory than were the projections made from the fully stocked empirical yield tables.

Projection of inventories from the fully stocked empirical yields probably failed because a cross section of the current volume from a group of plots is not a good indicator of how the average plot will grow in the future. This seems especially true for older and understocked stands. Although growth data might be a good indicator of short-term stand growth, the long-term volume trajectory of a timber inventory remains difficult to predict.

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Introduction

In the 1979 resources planning act timber assessment and program (RPA), southern softwood timber inventories were projected to increase to 116 billion cubic feet by the year 2000, then to decline rapidly to 84.3 billion cubic feet by 2030 (U.S. Department of Agriculture 1982). This decline, coupled with concerns about inadequate softwood regeneration, hardwood encroachment, and measured declines in growth rates of pine, led to an effort to reappraise timber resources in the South in a study known as the fourth forest (U.S. Department of Agriculture 1988). For a reassessment of the timber situation, the timber resource inventory model (Tedder and others 1987) was used to produce 50-year timber inventory projections, and the timber assessment market model (TAMM; Adams and Haynes 1980) was used to predict the future economy of the forest products markets. Using both models made it possible to estimate future timber supply and demand and to analyze the effects of intensified management practices and a shifting species mix on future timber availability and stumpage prices.

The fourth forest study was the first implementation of TRIM in the South. In the 1979 assessment, the timber resource analysis system (TRAS; Larson and Goforth 1974) was used for inventory projections. But a shortcoming of TRAS is that during a simulation it cannot explicitly simulate changes in timber management actions and account for long-term timber-type transitions (Brooks 1987). The TRIM model was designed to over come those limitations; however, the results of TRIM softwood projections in the Southeast raised serious questions about the validity of the system.

The initial projections of southeastern (Florida, Georgia, North Carolina, South Carolina, and Virginia) inventories produced volume and growth projections that radically departed from historical trends. As can be seen in figure 1, projections of softwood inventory and growth depart from their historical counterparts measured by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) Unit. Though the model inputs were developed from FIA field data, the TRIM projections fell 17 percent short of the FIA growth estimate. For individual owner and species types, this difference was as high as 35 percent (Knight 1986a). Recent FIA surveys in the Southeast have documented an apparent leveling off and a subsequent decline in the softwood growth rate (Knight 1987). But these projections were far below the expectations of analysts familiar with the new data.

Mills (1987) examined several possible reasons for this departure from previous trends (fig. 1). These include definitional problems, data aggregation problems, model errors, and data errors. The study used data from two consecutive forest inventories in an attempt to validate TRIM. The objective was to develop model inputs with the techniques used in the fourth forest study and to compare 10-year projections with the 10-year field-measured growth and inventory volumes. A second objective was to examine the effects of inventory data aggregation on the outcome of the projections.

Though the model has had wide review, this was the first attempt to validate TRIM timber projections. The results indicated the need to modify assumptions about the type of yield tables appropriate for inventory projections. Presented here are a description of the TRIM model and its requirements, a review of yield table concepts, and the study results and their implications for further use of TRIM.

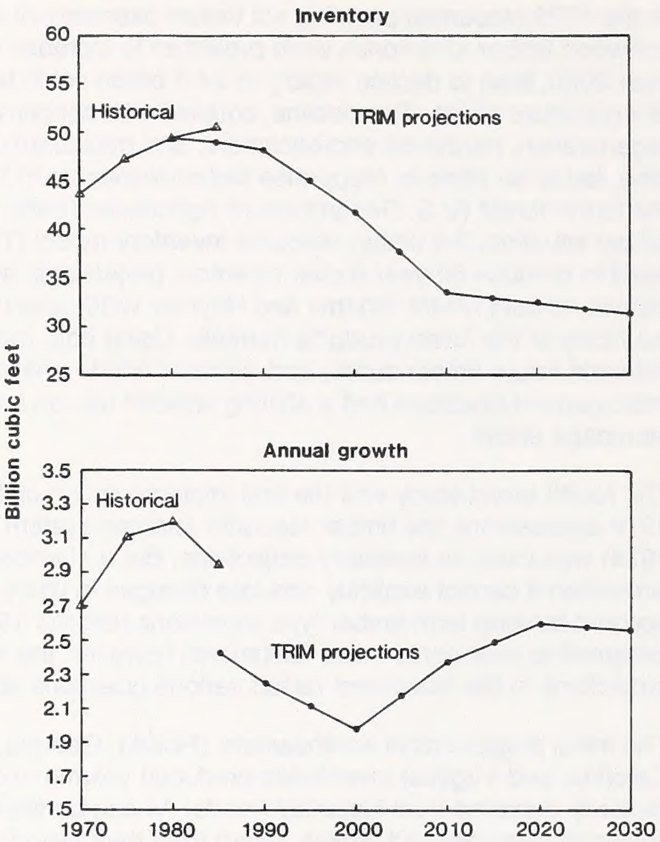

Figure 1—Southeastern softwood inventory and annual growth volume and TRIM projections produced early in the fourth forest study.

The Trim Model

A New Model

The timber resource inventory model was designed as a tool for predicting timber inventories in the course of analyzing regional timber policy. The model was originally developed to replace TRAS in the national RPA assessment program.[1] Previously, TRIM had been implemented in the Pacific Northwest Douglas-fir subregion (Flick 1984). From the stand level to the regional level there is demand for more detailed timber inventory projections. With the implementation of TRIM, the approach to regional modeling is allowed a higher level of sophistication.

The two models (TRAS and TRIM) use fundamentally different representations of inventory and projection methods. The inventory in TRAS is represented by a stand table of trees in 2-inch diameter classes. Growth and yield are simulated by changing the number of trees in the diameter classes. In the TRIM system, the inventory is aggregated into 5- or 10-year age classes, and growth is simulated by the use of yield tables and an approach-to-normal algorithm to project stand yield trajectories.

[1] The 1990 RPA national assessment used a new version of the model called the aggregate timberland assessment system (ATLAS).

Under the formal definition of simulation models, TRIM is not a growth model. It is a large bookkeeping system that requires input parameters that determine growth, yield, and harvest actions. These parameters can account for site, stand age, and stand density characteristics. An "open framework" design is what makes the model flexible enough to be implemented for the different timber types nationwide. The method TRIM uses to calculate growth and future stand volumes is very simple; however, the system and its many options can leave a first-time user feeling a little overwhelmed. The following sections briefly describe the representation of inventory and the role of management parameters in growth and harvest calculations.

The TRIM Inventory

Timber inventories consist of acres and their associated growing-stock volume per acre (usually in net cubic feet to a 4-inch top). For TRIM projections, timber inventories are aggregated into units by characteristics such as owner, species type, and site. This aggregation depends on user objectives and the availability of model parameters such as growth, yield, and harvest information. In the South's fourth forest study, inventory was aggregated by two geographical areas, six ownership groups, five species types, and three site productivity classes. The 84.8-million-acre southeastern inventory was represented by 90 inventory units (U.S. Department of Agriculture 1988).

Within each inventory unit, acres and volume per acre are arrayed by age class. Age classes are usually in 5- or 10-year intervals, and 18 age classes are often used. Within each age class, the inventory can be distributed across three stocking classes. Thus, 54 cells of an 18 by 3 matrix of acres and volume per acre are available for the regular inventory. Each inventory unit has four additional arrays available to further segregate acres into management classes. During a simulation, acres can be moved between these arrays to represent changes or trends in management practices. Alternate management arrays are dimensioned with one stocking level, which makes 18 available cells (18 age classes). Thus, an ownership-type-site inventory unit can be represented by 126 cells (54+(4×18)). Each cell represents an aggregation of several individual stands (or plots). In the fourth forest study, 182 million acres were aggregated across 180 inventory units that potentially had 22,680 available cells (not all owner-type site inventories existed).

Each inventory unit developed for a TRIM simulation is assigned a set of parameters that "manage" the projected acres through time. Each management intensity also requires a set of projection parameters. Many of these parameters are arrayed by age class: proportion of volume in softwood, percentage of growth on harvest, proportion of harvest, and the yield table volume per acre.

The TRIM yield table represents net volume per acre by age class for each specific species type, site, and management scheme. Stands do not necessarily attain the yield table volume; the yield tables in TRIM act as growth guide curves. The volume per acre associated with the initial inventory (in each cell) is calibrated to the yield table by use of a relative volume stocking[2] ratio. This ratio is the inventory volume per acre divided by the yield table volume per acre and is calculated for each age

[2] The definition of stocking used by the FIA and most references to stocking in the literature are based on site utilization that is a basal-area tree-density relation (see McClure and Knight 1984). For large aggregations of plots, this field measure of stocking relates directly to a volume-production measure of stocking (McWilliams and Birdsey 1986).

class. In subsequent periods of the simulation, stand volume is determined by multiplying the stocking ratio times the yield table volume in the next older age class. When the stand stocking is assumed to approach the normal condition, the stocking ratio can be adjusted for each period with an approach-to-normal equation (discussed later). This method has been described by Chapman (1924) as a technique for predicting the growth and yield of empirical timber stands by use of a normal yield curve.

Net growth calculated by TRIM is simply the change in net volume per acre from one period to the next. Growth can be thought of as the mathematical derivative of a stand's yield trajectory. The validity of calculating growth and yield from the same curve has been demonstrated; Buckman (1962) describes yield as increments of growth, and Clutter (1963) used the term "compatible growth and yield" for a loblolly pine model that derived stand yield by the mathematical integration of the growth function.

Harvested acres can either be taken out of the inventory or be regenerated. The initial condition of regenerated acres is determined by a stocking ratio supplied by the user. Two basic methods have been used to determine this initial yield table relation. Both methods calculate the ratio as a weighted average (by acres) of existing inventory volume divided by the yield table volume. One method uses all the inventory to calculate an overall weighted average; the other partitions the inventory and uses a specific part of it. Using only inventory that was less than 30 years old, Flick (1984) calculated the average stocking ratio in each age class. Each value was discounted back to the first age class with an inverse form of the approach-to-normal function and then averaged. Flick argued that younger stands represent current regeneration and management techniques, whereas older stands possibly were influenced by cutting or other disturbance. The method used for the study presented here included all the inventory acres in the calculation without discounting values by age class. The assumption was that natural pine stands would regenerate themselves at the average stocking density. After regeneration, the stand-stocking ratio was adjusted by use of the approach-to-normal relation.

Yield Tables

Yield tables have been used since the 18th century for predicting inventory growth and volume (Spurr 1952). Regional timber projections require yield tables that represent growth for an aggregation of many individual tree species. Since few such yield tables exist, they must be developed for the model. This section is intended to provide background on yield tables and to illustrate their development from inventory data.

Two basic types of yield tables described by Chapman (1924) and Spurr (1952) are normal and empirical yield tables. These are different representations of per-acre volume measured by stand age. The normal yield table represents volume per acre from only fully stocked natural stands within a site class. Normal yield curves are derived from the very best undisturbed stands and should represent the highest growth attainable for a particular timber class.

In contrast, empirical yields represent the current condition of a particular timber class. Empirical yields are derived by measuring the volume per acre (by age) for an entire range of stocking densities within a site class and averaging them.

One variation of normal yields is known as "well-stocked" yield tables. Well-stocked yields are developed from an upper range of stand densities. This range includes stands of less than normal, but above average, stocking. These yield tables may be more useful than normal yield tables as a management tool because the well-stocked condition is more often found in the field than is the normal condition (Farrar and others 1986).

The term "well-stocked" was used by Schumacher and Coile (1960) to describe the yield tables they derived for southern pines. They defined stocking as a measure of ground-area use (density) based on standards of diameter class, trees per acre, and basal area per acre. Well-stocked stands are considered to have a stocking measure of 100 percent or more. The yield tables developed from plot measurements on these stands were aggregated by species, site, and age.

McClure and Knight (1984) use the method of well-stocked yields to develop what could be called fully stocked empirical yields for southern pines. The term "fully stocked," previously associated with normal condition, is used to describe stands with 100- to 132-percent stocking based on FIA stocking standards. McClure and Knight considered these yields compatible with those developed by Schumacher and Coile (1960).

Two types of yield tables have been used with TRIM to project timber inventories in different regions. For the projections in the fourth forest study (U.S. Department of Agriculture 1988), Knight developed fully stocked yield tables. In a timber study of western Oregon and Washington, Flick (1984) used what he called normal yield tables for simulations.

Approach to Normal

The approach-to-normal concept assumes that stand stocking is not constant but approaches the normal condition as stands fully utilize the site. Given enough time, the volume in all stands would likely approach the normal-yield-curve volume. Much work was done on this concept in the 1920's and 1930's (Chaiken 1939). Chapman (1924) stated that when normal yield curves are used for a single stand, over time the relative stand density can be expected to approach the normal-stocking density. Chaiken (1939) studied data from remeasured Virginia and loblolly pine plots and reported that older stands were closer to normal stocking than were younger stands; younger stands approached normal stocking faster than older, understocked stands; and poorly stocked stands approached normal faster than better stocked stands. Schumacher and Coile (1960) examined stocking trends from remeasured loblolly pine plots in North Carolina and found that these stands asymptotically tended toward their measure of 100-percent stocking. The fourth forest study and the study presented here use the approach-to-normal function in TRIM to asymptotically adjust the stocking ratio for each period. The equation and its parameters are discussed in the next section.

Application of TRIM With Natural Pine in North Carolina

The timber resource inventory model was used to project a timber inventory for the 10-year-remeasurement period for North Carolina (1974 to 1984). The natural pine type was chosen for use in all projections.

It represented the largest sample of plots when the North Carolina data were aggregated to the same five species types projected in the fourth forest study (natural pine, planted pine, mixed pine-hardwoods, upland hardwoods, and bottomland hardwoods). Model parameters were developed to simulate what was reported to have occurred in the field as closely as possible. Within the respective sampling error, the FIA data were assumed to be accurate. The FIA data set is discussed in more detail in the appendix.

Evaluation Criteria

The data set derived from the 1984 FIA field measurements was used in evaluating the 1984 TRIM projections. This data set was considered to accurately represent the current condition of the inventory. Deriving growth and harvest figures from the data was difficult because of the recorded decline in acreage of natural pine between 1974 and 1984 (discussed later). If there was a definitional difference between projected and measured growth, they would not be the same. Thus, the evaluation of TRIM was weighted toward the 1984 projections of inventory volume.

Most authors agree that no projection system can perfectly represent the real system being modeled (Buchman and Shifley 1983). Error is assumed to exist in TRIM projections as it does in field measurements. Because the error in projections was not known, the evaluation criteria were developed from the sampling error reported for the field measurements. Projections were rated (1) successful, (2) marginal, or (3) unsuccessful, depending on which of the following criteria they met:

1. A successful inventory projection is within the reported sampling error for the 1984 field-measured inventory.

2. A marginal projection is one in which the error region around the field inventory overlaps the error region around the projected inventory. The starting TRIM inventory and the projections are assumed to have the same error that was associated with the field measurements.

3. An unsuccessful projection falls outside the region with overlapping errors for projections and field measurements. The simulation is also considered unsuccessful if projected inventory meets this criterion and projected growth meets a higher criterion (this indicates a problem in definition of growth).

This evaluation might be criticized because it lacks statistical rigor in testing results (see, for example, Reynolds 1984). The error associated with TRIM projections was not calculated. Though the objectives of this study were to project aggregate inventories by the methods used in the fourth forest study, determining confidence intervals surrounding individual TRIM projections by making predictions with a series of individual plots may be possible. This effort should be pursued as future research.

Testing Aggregation

The evaluation criteria were used to appraise inventory projections that were aggregated at two levels. Simulations that projected inventory for three site classes were compared with simulations projecting one aggregate site (no site representation). If projections for both met the same evaluation criteria, the aggregation of inventory by site class was considered to have no effect on the outcome.

This test was repeated for two geographic areas. All acreage of natural pine in North Carolina represented one geographic area; natural pine acres in the nonindustrial private ownership in survey unit 3 (see the appendix), the other.

Though TRIM allows acreage in each age class to be distributed across three stocking classes, the beginning inventories were aggregated into one stocking class. The model uses a simple proportioning scheme to project acreage within these stocking classes. Carrying one average stocking class was determined to project the same total inventory and growth that carrying the inventory in three stocking classes did. This reduced the amount of model input and output and simplified tracking acreage and growth.

Developing Yield Tables

Three basic sets of yield tables were developed from the North Carolina data to test the TRIM growth mechanism. The first set was fully stocked empirical yield tables developed by methods similar to those used by McClure and Knight (1984). The second was called growth yield tables because they were developed from growth data. The third set was called composite yield tables and was developed as a sensitivity analysis tool; these tables are not presented here (for details, see Mills 1987).

Fully stocked empirical yields were derived from the FIA plots with 100- to 132-percent FIA natural pine stocking. Volume was aggregated by age class, and the average volume per acre was plotted. The yield curve was derived by drawing a freehand curve through the plotted points. These yields (see appendix) were almost the same as the original natural pine yields developed for the fourth forest study (U.S. Department of Agriculture 1987). Figure 2 illustrates an empirical yield curve and the fully stocked inventory from which it was derived. Figure 2 also contains a growth yield curve developed from the same data set.

Growth yields were an experimental alternative to empirical yields. The model treats growth as the result of incremental change in inventory volume and assumes that growth and yield are strictly compatible. Using growth data to develop yield tables was an attempt to compare the field-measured growth with the growth derived from inventory volume curves (fully stocked empirical yields). The growth values from all 1984 remeasured permanent plots were used because they were hypothesized to represent the growth in the entire inventory between 1974 and 1984.

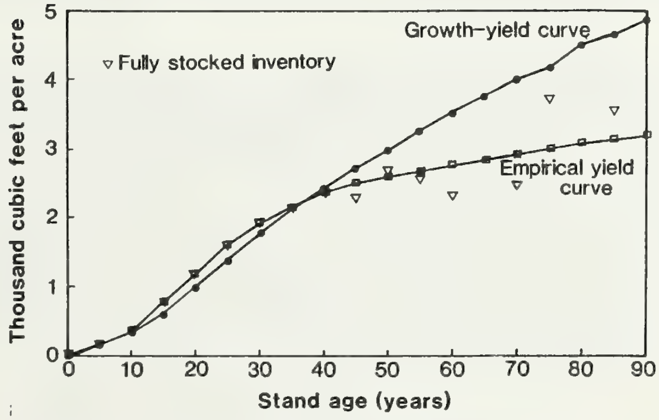

Figure 2—Inventory volume of fully stocked natural pine stands plotted with the corresponding fully stocked empirical yield curve and growth yield curve.

The first step in the development of growth yield tables was the aggregation of annual growth within age classes. The next step was to calculate 5-year average growth per acre for each age class. This growth per acre was then summed, starting with the first age class and adding the 5-year growth for each successive class. The final result was a yield table for which the volume-per-acre value in any one age class was really the summation of net growth per acre measured in that age class and all younger age classes (adjusted to midpoint values). As is illustrated in figure 2, the growth-yield volume growth in older stands was higher than fully stocked empirical yield volume growth.

Approach-to-Normal Equation

During a TRIM simulation, stand stocking can be adjusted through an approach-to-normal equation with parameters supplied by the user. Below is the equation used in this analysis:

$$S_{i+1} = S_i b_1 + b_2, \tag{1}$$
$$S_{i+1} = (S_i + S_i b_1 + b_2)/2, \text{ and} \tag{2}$$
$$A = b_2/(1-b_1); \tag{3}$$

where

S = stocking ratio,
i = projection period,
b_1 = coefficient term,
b_2 = intercept term, and
A = asymptote, when b_1 and $b_2 > 0$.

Equation (1) calculates the "full approach" to normal, and equation (2) provides the new stocking ratio at the "half approach" rate. The stocking asymptote is calculated with equation (3). For this study, the asymptote was considered to be the yield table (where $b_1 = 0.90$ and $b_2 = 0.10$). Under empirical yields, the full approach function was used for stand ages 0 to 42, and the half approach for ages 43 to 62. No change in stocking was allowed past stand age 62. When growth yields were used, an assumption was made (based on an observation of the data) that stand volume approached the yield table volume for all age classes. Therefore, equation (2) was used from age 43.

Area Change

The FIA data indicated a substantial decline in acreage of natural pine in North Carolina between 1974 and 1984; statewide, by 18.8 percent (1.07 million acres). Coupled with this loss was a change in the distribution of acreage among site classes. Although site classes 2 and 3 experienced substantial declines in acreage, the number of acres recorded in site class 1 increased 71 percent in 1984. Projections by TRIM were configured to make shifts in acres that would come as close as possible to the changes measured in the field. Under simulations for one average site, acreage of natural pine declined; under three-site simulations, the shift among site classes for acres was modeled. For a more detailed description of this process, see "Modeling Area Change" in the appendix.

Harvest

Two levels of harvest were used in all simulation schemes so the sensitivity of inventory and growth projections to timber harvests could be examined. A base-level harvest was calculated directly from the data set and aggregated by age class. The base-level harvest was then reduced and a second set of projections was made. Both levels of harvest were applied to the inventory over a range of age classes (for details, see "Harvesting" in the appendix).

Projections

Projections were made by use of the personal computer timber resource inventory model (PC-TRIM) on a microcomputer. The simulation was extended past 1984 and the harvest and area held constant to 2024.

Projection Results

The inventory statistics derived from the FIA data sets are summarized in tables 1 and 2. The results of TRIM projections representing North Carolina for the State and survey unit schemes are summarized in tables 3 and 4. Projection results for the State are shown in figures 3 and 4; for survey unit 3, in figures 5 and 6.

The FIA data summaries are the inventory, growth, and harvested volumes derived from the data sets. A calculation was made with the FIA data set called the growth-drain identity. This equaled 1974 inventory, plus 1974 to 1984 growth, less 1974 to 1984 harvest. The 1984 growth-drain identity calculated from table 1 equals 7,269 million cubic feet. It is 8.9 percent less than the 1984 inventory value and outside the range of any sampling error. In part, the reason for this may reflect an inability to "capture" all the 1974-84 growth from the data set (explained later). The FIA report of growth for the natural pine type in North Carolina was 3.4 billion cubic feet (Sheffield and Knight 1986); it brings the growth-drain calculation within 4.9 percent of the 1984 inventory measurement. If all components of the growth-drain equation are adjusted within their respective sampling errors, a 1984 inventory of 7,943 million cubic feet can be calculated (0.1 percent low). If the FIA reporting of growth is presumed correct, the growth-drain calculation can meet test criterion 1.

A growth-drain calculation for the statistics from survey unit 3 is very close without adjustment for sampling error. From table 2, the 1984 calculated inventory is within 1 percent of the 1984 value, meeting criterion 1.

Table 1—Inventory statistics derived from forest inventory and analysis data for the natural pine type, all ownerships, North Carolina, 1974-84

Natural pine type and year	Net volume	Sampling error[a]
	Million cubic feet	*Percent*
Inventory (thousand acres):		
1974 (5,891)	7,545	2.0
1984 (4,731)	7,951	2.1
Growth, 1974-84	3,125	2.0
Harvest, 1974-84	3,401	5.3

[a] Interpolated from tables in Knight and McClure (1975) and Sheffield and Knight (1986).

Table 2—Inventory statistics derived from forest inventory and analysis data for the natural pine type, survey unit 3, nonindustrial private ownerships, North Carolina, 1974-84

Natural pine type and year	Net volume	Sampling error[a]
	Million cubic feet	*Percent*
Inventory (thousand acres):		
1974 (1,827)	2,520	3.6
1984 (1,426)	2,534	3.7
Growth, 1974-84	1,003	3.6
Harvest, 1974-84	964	9.9

[a] Interpolated from tables in Knight and McClure (1975) and Sheffield and Knight (1986).

Table 3—Timber resource inventory model projections of inventory and growth for the natural pine type, all ownerships, North Carolina, 1974-84

	Projections with empirical yield tables		Projections with growth yield tables	
Projections	Net volume	Evaluation criteria[a]	Net volume	Evaluation criteria[a]
	Million cubic feet		*Million cubic feet*	
With base harvest:				
Beginning inventory	7,545		7,545	
Base harvest	3,402		3,402	
Growth	2,036	3	2,734	3
Ending inventory	6,179	3	6,877	3
With reduced harvest:				
Beginning inventory	7,545		7,545	
Reduced harvest	2,540		2,540	
Growth	2,032	3	2,808	3
Ending inventory	7,036	3	7,814	1

[a] 1= successful; 2= marginal; 3= unsuccessful.

Table 4—Timber resource inventory model projections of inventory and growth for the natural pine type, survey unit 3, nonindustrial private ownerships, North Carolina, 1974-84

Projections	Projections with empirical yield tables		Projections with growth yield tables	
	Net volume	Evaluation criteria[a]	Net volume	Evaluation criteria[a]
	Million cubic feet		*Million cubic feet*	
With base harvest:				
Beginning inventory	2,520		2,520	
Base harvest	964		964	
Growth	716	3	962	2
Ending inventory	2,273	3	2,520	1
With reduced harvest:				
Beginning inventory	2,520		2,520	
Reduced harvest	868		868	
Growth	712	3	964	2
Ending inventory	2,364	2	2,617	1

[a] 1= successful; 2= marginal; 3= unsuccessful.

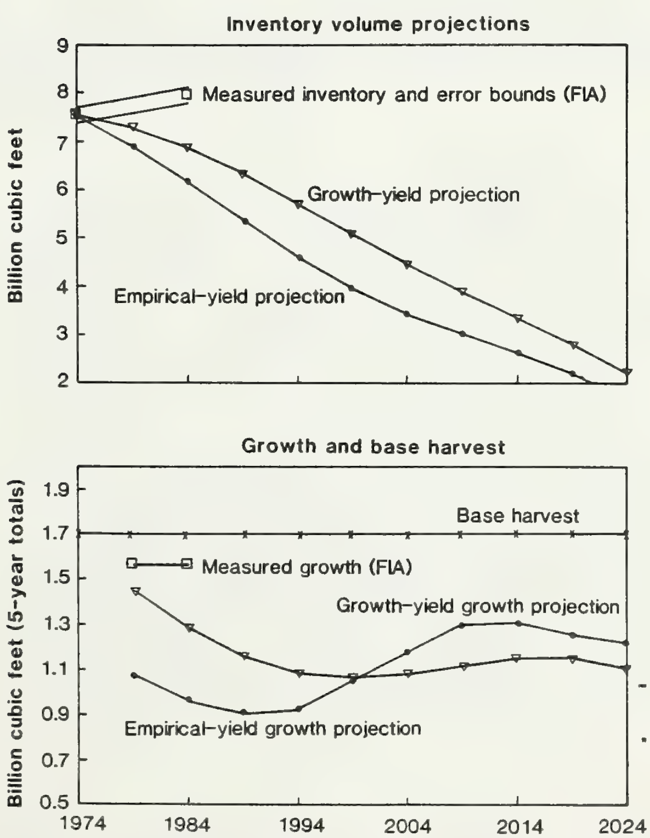

Figure 3—Statewide inventory projections with base harvest and FIA measurements representing the natural pine type in North Carolina.

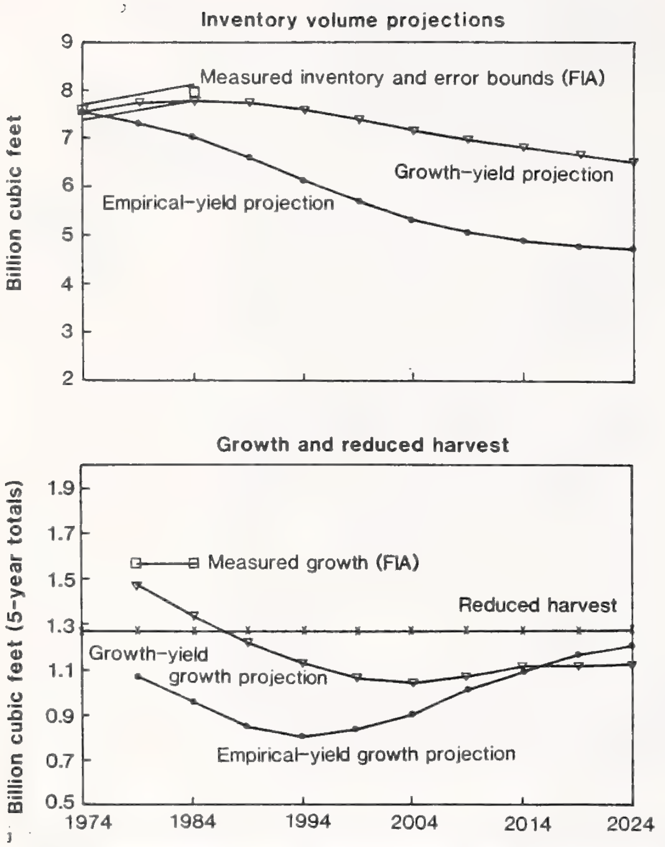

Figure 4—Statewide inventory projections with reduced harvest and FIA measurements representing the natural pine type in North Carolina.

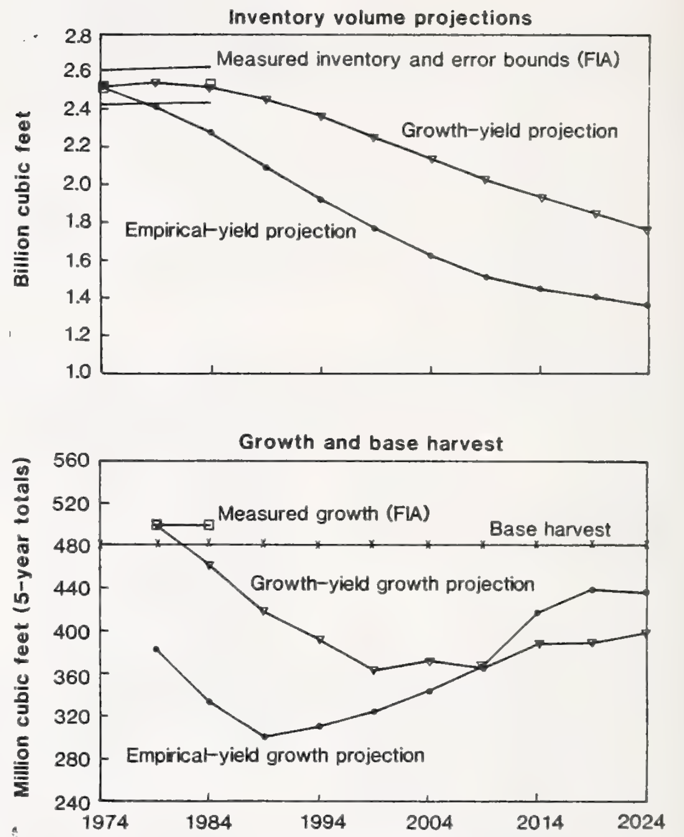

Figure 5—Survey unit 3 inventory projections with base harvest and FIA measurements representing the natural pine type in nonindustrial private ownership in North Carolina.

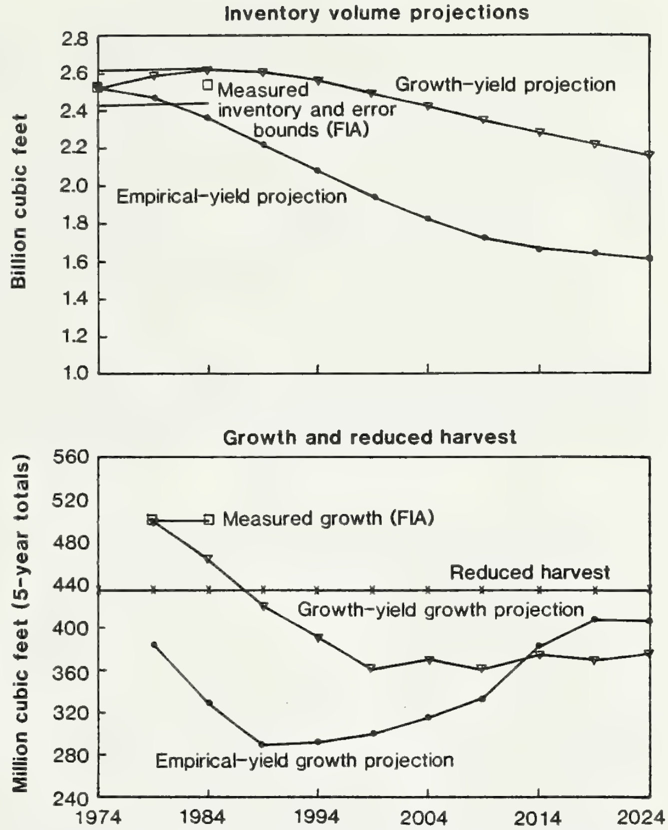

Figure 6—Survey unit 3 inventory projections with reduced harvest and FIA measurements representing the natural pine type in nonindustrial private ownership in North Carolina.

Discussion

As the results show, all inventory and growth projections made by use of the fully stocked empirical yield tables failed to meet the first criterion. Most projections made from the growth yield tables met the "successful" criterion. Growth yield tables produced more growth than did empirical yield tables, and higher inventories were thus maintained. At the State level, all projections were better than the empirical yield simulations, but the first criterion was not met until harvest was reduced. For the survey unit, all projections of inventory met the first criterion.

The results show that projected growth was insensitive to the level of harvest used. As the harvests were reduced, total growth remained about the same, whereas projected inventory volumes increased by the change in harvest volume. The model was regenerating pine after harvest, and this indicates that regenerated pine was projected to grow at the same rate as the pine being harvested. Growth declined when natural pine acreage was removed from the land base and not regenerated. In the long term, growth increased as the level of harvest caused a shift in the stand structure to younger, faster growing, age classes. Harvest occurred in a range of age classes. If harvest had been shifted to the oldest age class (slower growing), a reduction in harvest would have caused a reduction in total growth.

Under base harvests, the statewide inventory projections were much farther off "target" than were the survey unit 3 projections. It is not clear why the projection results were dissimilar. Differences in yield tables and differences in area change did not appear to be a factor. One explanation might be the harvest level as a percentage of beginning inventory; the 10-year base harvested volume, as a percentage of beginning inventory volume, is 38 percent of the survey unit inventory and 45 percent of the statewide beginning volume. When statewide harvests are reduced to 34 percent of beginning inventory volume, the statewide and survey unit projections are similar. The survey unit harvest level is possibly too low because the harvest was calculated only from acres still in the nonindustrial private ownership in 1984. Acres removed from the ownership between 1974 and 1984 could have been purchased by the forest industry owner group and harvested. That harvest volume would not be added into the value applied to the 1974 inventory. When this value is significant, the survey unit inventory projection can be expected to behave like the statewide base projection.

Aggregation

Most three-site inventory projections met the same criteria as the aggregate site inventory projections. Because of this, the inventory aggregation by site class was concluded to not influence the 10-year projections.

The fourth forest study was an effort to examine regional timber supply trends with aggregate timber inventories. The objective of aggregation is to simplify the modeling process by reducing the size of model inputs and model outputs. Aggregation also increases the confidence level surrounding model predictions. To expect TRIM to accurately project volume for a single acre based on data from one inventory plot would be unreasonable because of the high amount of variation assumed to surround the growth measured on individual plots. As the data from a large number of plots are aggregated, the average growth can be expected to follow some general trends. The general trends are predicted at the regional level. When projections of aggregate inventories fail to predict general trends, as they did with the fully stocked empirical yield tables, then the objectives have not been met.

Growth and Yield

The failure of projected growth to match field values was common to most projections. Davis and Johnson (1987) discuss the use of yield tables in timber projection systems and present a similar problem experienced on the Boise National Forest. Empirical yield tables were derived for ponderosa pine from plot data representing all levels of stocking. The yield curves flattened out in the older age classes, which indicated no net growth should be occurring. But the net growth derived from field measurements was higher for the older stands than the yield tables would predict.

In addressing this problem, Davis and Johnson (1987) suggest that stand mortality may be underestimated by field crews. This would lead to the overestimation of net growth because net growth is calculated by subtracting mortality from gross growth. They argue that stand mortality plays another role over time by periodically reducing volume through the effects of insects and fire. All past epidemics of mortality affect the current condition of a timber stand. Thus, the flattening of an empirical yield curve might be the result of past reductions in volume rather than a lower growth rate. Davis and Johnson say,

> Part of the problem surely lies in the methodology of using cross-sectional data to estimate growth over time. The stands sampled for empirical yield show how different stands grew over time, not how the same stand grew.

As figure 7 shows, a yield curve can be plotted through a group of timber stands with the expectation that the yield volume trajectories will coincide over time. But instead, these stands may have independent trajectories. The yield table in figure 7 will underestimate current growth, and hence, future inventory volume.

Natural pine stands in North Carolina are subject to volume-reducing events—insect infestations, wildfire, disease, and wind and ice storms (Knight and McClure 1975). They are also subject to partial cutting (thinning, selective cutting, and high grading). The net stand volume is expected to decline after a disturbance, but the measurable net growth may temporarily decline from high mortality and later increase. An example of steady net growth in a stand subject to thinning can be seen in figure 8. Thinning can "capture" mortality; over time, thinning reduces the average stand volume, whereas average growth is always positive. The average volume per acre for a group of thinned stands might appear along the dotted line in figure 8. But, as in the example from Davis and Johnson (1987), the individual stand volume trajectories would look quite different and cumulative growth would be much higher than data on inventory volume per acre would suggest.

As justification for his use of normal yield tables in TRIM, Flick (1984) reasoned that true empirical yield tables would underestimate the growth potential of undisturbed stands because they include stands that have previously been subject to volume-reducing disturbances. Should the fully stocked stands selected for the development of the empirical yield tables reflect the effects of past disturbances?

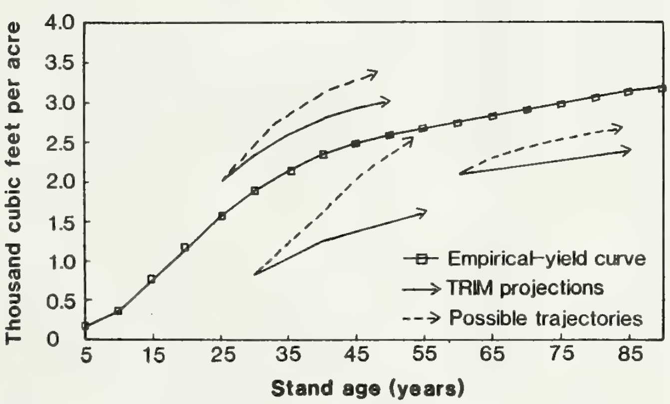

Figure 7—Inventory volume with a fully stocked empirical yield curve showing TRIM volume projection and possible independent trajectories of individual stands; adapted from Davis and Johnson (1987).

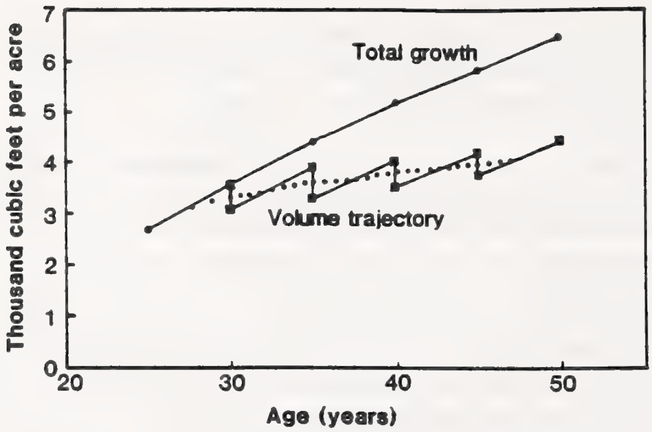

Figure 8—Volume trajectory and accumulation of growth in loblolly pine stands subject to multiple thinnings; adapted from Clutter (1963).

The data indicate that fully stocked stands represented 45 percent of all natural pine acreage statewide and 61 percent of all natural pine acreage in survey unit 3. Between 1974 and 1984, about 2.3 percent of all natural pine acreage was annually disturbed by partial cutting or natural phenomena. If independence is assumed, potentially 23 percent of the acreage in natural pine lost volume from disturbance in 10 years. Because of this, probably few acres in the older age classes have been free of disturbance, which would support Davis and Johnson's (1987) theory. A curve through a cross section of the current volume in older stands would not predict the future growth rate because disturbed stands lower the average volume which lowers the curve. The effects of disturbance are included in fully stocked empirical yield tables and these effects biased the growth predictions.

Net Change

Figure 9 shows the statewide average volume per acre of natural pine in North Carolina from the 1974 and 1984 FIA data and the average site yield curves. The average volume per acre increased in almost all age classes between 1974 and 1984.[3] The solid lines between inventories represent average 10-year "growth trajectories" made by the 1974 inventory. Reasons for an upward net change could include both growth on growing stock and the harvest of stands with less than average volume.

If this 10-year trajectory in inventory volume is compared with the yield tables in figure 9, why growth yields were more successful than empirical yields becomes obvious. When the approach-to-normal function is invoked in TRIM, plotted inventory projections appear parallel to the yield curve. The 10-year trajectories of average volume per acre appear to parallel the growth yield curve, not the empirical yield curve.

[3] This study did not investigate the variability that surrounds the average volume in each age class. Though the 1984 average volumes may not be significantly different from the 1974 values, they are consistently higher.

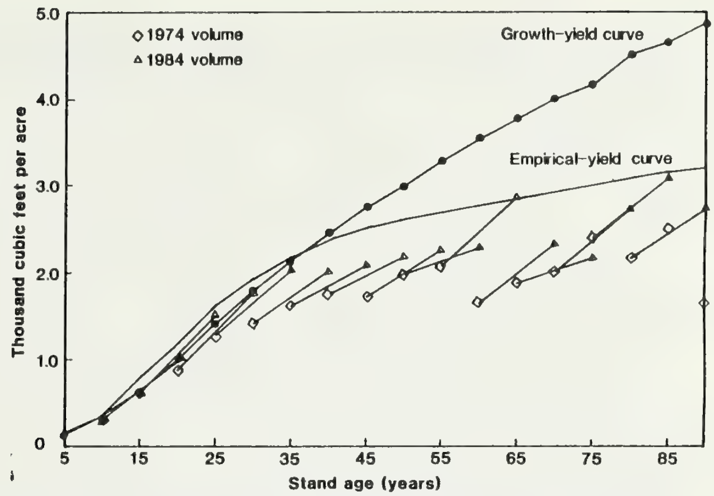

Figure 9—Average natural pine inventory volumes in North Carolina from the 1974 and 1984 FIA measurements and the average-site yield curves used for inventory projections. Lines connecting the 1974 and 1984 inventory volumes represent a 10-year "trajectory" of average volume.

This upward trend in the inventory volume represents a "snapshot" of the average volume per acre for only a 10-year period. This upward trend in volume cannot be expected to continue for two reasons. First, as was discussed, stand volume is assumed to approach the normal stocking level asymptotically. On undisturbed acres, this increase in stocking is expected to level off at some volume for which there are only a few stands. The second reason goes back to what Davis and Johnson (1987) presented and the data supported. These stands are subject to periodic volume-reducing disturbances. At some point in the future, the average volume per acre could be expected to decline in one or several age classes.

Conclusions

The analysis presented here was an effort to validate TRIM inventory and growth projections by comparing them to field measurements. The objective was to model natural pine in North Carolina between 1974 and 1984 and to examine the model's projected inventory and growth under two methods of inventory aggregation. The measured growth, harvest, and area data were used in an effort to simulate, as closely as possible, what took place over the 10-year remeasurement period.

The results indicate that fully stocked empirical yield tables developed from cross-sectional inventory volume do not adequately project stand growth. Individual stands are subject to disturbances that affect their volume trajectories. The empirical yield curves flatten off and produce little growth in the older age classes, whereas the inventory data indicated that growth was higher in these older stands.

Based on the evaluation criteria, yield tables developed from growth data were more successful in projecting inventory volume than the yield tables developed from volume data. They were derived from plot growth measurements and should be considered compatible yield tables for TRIM projections. Growth yield tables did not generate as much growth as the field data reported; however, the approach-to-normal function could be calibrated with the field data, and this might increase projected growth.

Under the criterion established to evaluate the results, no significant differences could be found between projections of different aggregations. Projection results of an aggregate inventory did not differ significantly from those when the inventory was in three site classes. Also, a 25-percent reduction in the statewide harvest was found to have no effect on the amount of 10-year projected growth.

This study illustrates the variation possible when timber volume is predicted from different yield tables. Caution should be exercised when growth yield tables are developed and used to project stands into the future because growth may vary by period, or may be subject to long trends (that can reverse). Yield tables derived from growth data represent growth from a specific time interval. Growth is influenced by such things as weather and disease patterns and changes in management practices. Statewide, the measured growth in natural pine acres in North Carolina declined 21 percent between the 1974 and 1984 measurements. What bias is introduced by calibrating a 50-year volume projection with 5 or 10 years of growth data? Could this method be more suitable for short-term, rather than long-term, projections? The growth-yield method, however, is a better system for use with the TRIM model than is the use of fully stocked empirical yield tables (current volume per acre).

The final softwood projections from the fourth forest study have higher levels of timber volume and growth in the South than do the projections shown in figure 1. Reasons for the increase include improvements in handling area shifts, greater use of yield tables reflecting more intensive timber management practices, calibration of the approach-to-normal function, and implementation of growth-yield tables for natural pine.

Though much work has been done, many questions remain. Ways to develop yield tables that represent growth potential rather than current stand condition are needed. Are growth-yield tables related to normal yield curves? Would normal yield tables improve these projections? Can the approach-to-normal relation be calibrated or improved? Should periodic disturbances that temporarily reduce stocking be modeled? The TRIM model satisfies the requested harvest by "cutting" the average volume per acre in each age class treated. Does the number of acres required to fulfill this requested harvest volume approximate the number of acres being cut in the field? Finally, can partial cutting be implemented in TRIM to project uneven-aged stands that are subject to multiple cuttings such as northern hardwoods?

Timber policy is shaped by assumptions about the future. The fourth forest study is part of an effort to achieve an "optimal" future for society by an examination of the long-term economic implications of alternative timber management actions for the South. If the models are not trusted, then the modeling effort takes a narrower focus and the results may reflect only the preconceived notions of those doing the study.

Acknowledgments

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Appendix

History of TRIM

The timber resource inventory model was developed at Oregon State University, Corvallis, OR, between 1982 and 1985. The design was based on the timber resource economic estimation system (TREES) (Tedder and others 1980). The TREES model was developed at Oregon State University by K. Norman Johnson, H. Lynn Scheurman, and John H. Beuter for use in a comprehensive analysis of the timber resources in Oregon (Beuter and others 1976). Both models have many of the same data requirements and algorithms, but improvements in TRIM include better organization and reporting of model inputs and outputs, and input error checking. The TRIM model does not have harvest optimization options like those in the TREES model. Harvest in TRIM is specified by the user, and thus the model can be classified as deterministic.

The mainframe version of TRIM was continually modified throughout the fourth forest study. The final version is maintained by Jonna Kincaid at the University of Washington, Seattle. The version of TRIM used for this analysis runs on microcomputers (PC-TRIM). It was converted from an early mainframe version through the effort of K. Norman Johnson, John R. Mills, and others at the College of Forestry, Oregon State University.[1] Errors that existed in the mainframe version have been eliminated. The aggregate timberland assessment system (ATLAS) model used by the Forest Service in the 1989 RPA Timber Assessment represents another evolutionary step in the TREES/TRIM system. The sequencing of growth and harvest in ATLAS make it similar to PC-TRIM, but ATLAS is a new (and smaller) program that includes a partial cutting harvest option.

Inventory Data Set

The data for this analysis were provided on magnetic tape from the Forest Inventory and Analysis Unit at the Southeastern Forest Experiment Station, Asheville, NC. The 1974 inventory of the natural pine type in North Carolina was represented by 1,662 plot summary records representing about 5.8 million acres. The 1984 inventory of the natural pine type was represented by 1,658 plots representing 4.6 million acres.

The data were aggregated to levels found in the publications by Knight and McClure (1975) and Sheffield and Knight (1986) and checked for accuracy. Each data set included net growing-stock volume, growth, harvest, mortality, and the associated acres by geographic location, owner, species, stand age, and stocking percent. The 1974 inventory data were used to develop the TRIM beginning inventory and all the fully stocked yield tables. The 1984 data set was used to derive growth, harvest, and area change parameters for the projections. The plot growth estimates were based on diameter and height measurements of trees on permanent inventory plots. The projections were evaluated with the 1984 inventory aggregated to the same levels as the beginning inventory.

Survey unit 3 contains the Piedmont region of North Carolina (fig. 10). The nonindustrial private forest (NIPF) ownership of natural pine type in survey unit 3 was represented by 432 plot summary records (1.9 million acres) in 1974. This region contained 31 percent of the North Carolina timberland acres, 32 percent of the softwood inventory volume, and the most harvest and mortality (Knight and

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[1] The updated version of PC-TRIM is available from John Mills, USDA Forest Service, P.O. Box 3890, Portland, OR 97208-3890.

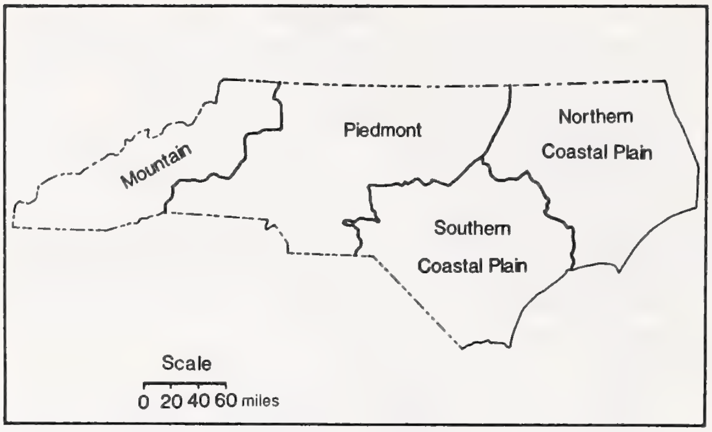

Figure 10—FIA survey units in North Carolina.

McClure 1975). Growth in the Piedmont was inflated by a large amount of ingrowth from old-field reversion to pine. Ingrowth accounted for 23 percent of the total growth, compared with 14 percent in the other regions. This growth rate was not expected to continue. The total 1974 growth rate for the State's timberland was up 21 percent from the 1964 measurement. Eighty-two percent of the total 1974 softwood inventory was in NIPF ownership.

All TRIM-run parameters were developed on the basis of a 5-year period; harvest, yields, land shifts, and so forth. Two complete cycles were required for the model to make a 10-year projection between 1974 and 1984. The midpoint year was 1979.

Projection Schemes

The projection schemes used in this study are presented below. All model inputs were developed consistently for each scheme.

1	2	3	4
Survey unit 3	Survey unit 3	Statewide	Statewide
NIPF owner	NIPF owner	All owners	All owners
Natural pine	Natural pine	Natural pine	Natural pine
3 sites	1 site	3 sites	1 site

Site Productivity Class

Site productivity class is presented by McClure and Knight (1984) as cubic feet of annual net growth per acre at the culmination of mean annual increment. Site class 1 includes all stands capable of producing at least 85 cubic feet per acre at culmination; site class 2 stands range from 85 to 50 cubic feet per acre; and site class 3, from 50 to 20 cubic feet per acre.

Yield Tables

The empirical yield tables were developed with net volume from fully stocked plots in the 1974 data set (fully stocked equals 100 to 132 percent FIA classification of stocking). In developing the statewide yield tables, 690 plot records were used, and 234 plot records for survey unit 3. (For a larger sample size for survey unit 3, the plots used for yield tables included all ownerships, not just NIPF owners.)

The volume data were aggregated into age classes, and an average volume per acre was calculated within each age class. In the final process, the averages were graphed by age class and a curve was projected through them by hand. In the past, the average volumes were "smoothed" with the regression of a cubic polynomial with volume per acre as the dependent variable and age, age squared, and age cubed as independent variables. The result required graphing and adjusting to smooth the end points. Both methods produced the same results. The full set of yield tables developed for North Carolina is shown in figures 11 and 12.

Another technique is to use weighted regression analysis with the individual plot volumes rather than the average volume by age class. This process provides statistical information about the variation of volume by age, and the resulting curve should be similar.

The growth yield tables represent a different concept because they were developed from measured growth on the inventory. Adding growth over the range of age classes is a representation of net inventory growth accumulated by age. With the definition of compatible growth and yield that Buckman (1962) and Clutter (1963) developed mathematically, the growth curves also represent net volume.

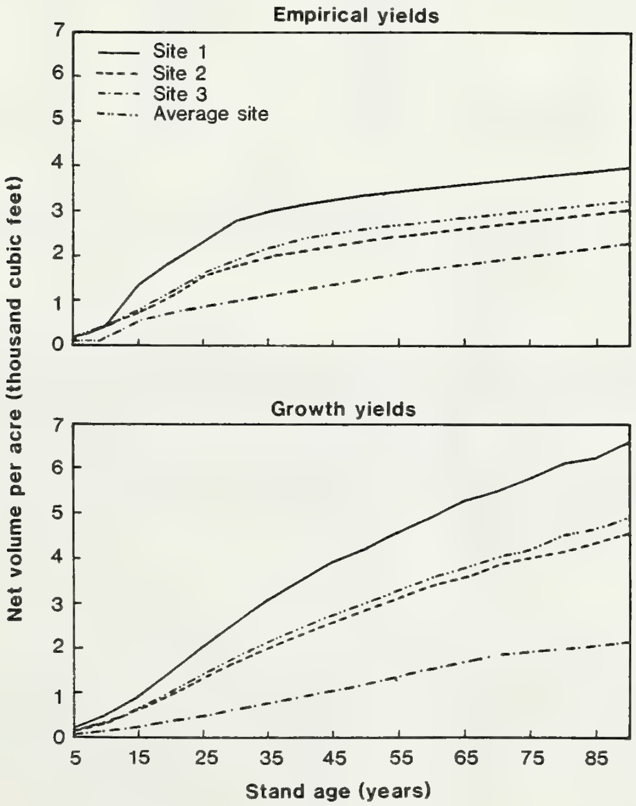

Figure 11—Fully stocked empirical yield curves and growth yield curves developed from the FIA measurements for the statewide natural pine projections.

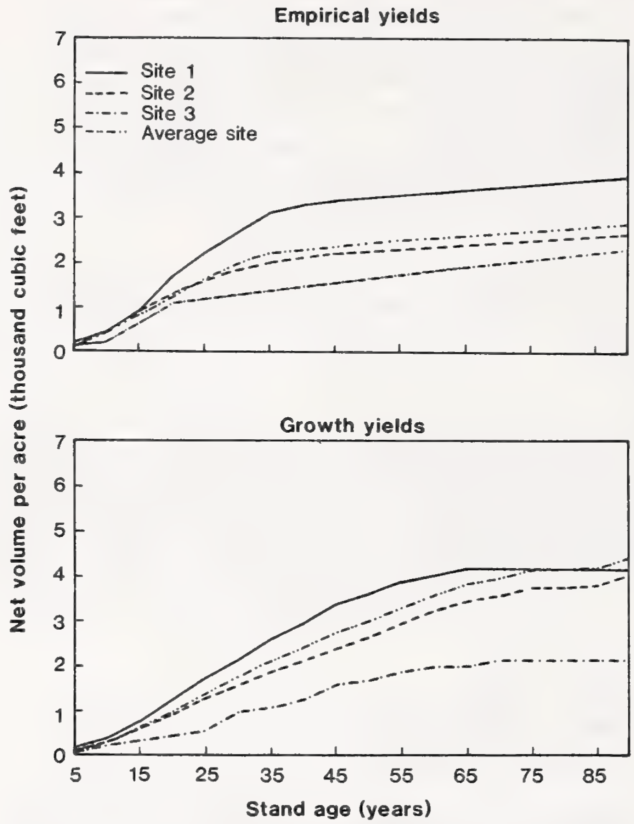

Figure 12—Fully stocked empirical yield curves and growth yield curves developed from the FIA measurements for natural pine projections of survey unit 3.

Modeling Area Change

Figure 13 illustrates the shifts in natural pine acreage measured 10 years apart. The biggest factors contributing to losses of natural pine were harvesting and land clearing followed by lack of regeneration, or regeneration to planted pine (Sheffield and Knight 1986). The major reason for the shift to site class 1 was thought to be the reclassification of Virginia pine to a higher site—probably caused by a difference in training the 1974 and 1984 field crews rather than a real improvement in site productivity (Knight 1986b).

The area changes were simulated with the model's donor shift and unstocked shift mechanisms. These two acre-shift methods were compared for each series of TRIM projections. The donor category represents timberland acres outside the inventory. The user supplies parameters to shift acres to and from this category. Acres can be moved out of the donor category and into specific stocking and age classes in the inventory. The actual volume depends on the yield table value and the initial stocking value. Acres cannot be withdrawn from the inventory by age class; instead, a proportion of the total acres in the inventory must be removed. When acres are moved from the inventory, acreage and volume are reduced in all age classes.

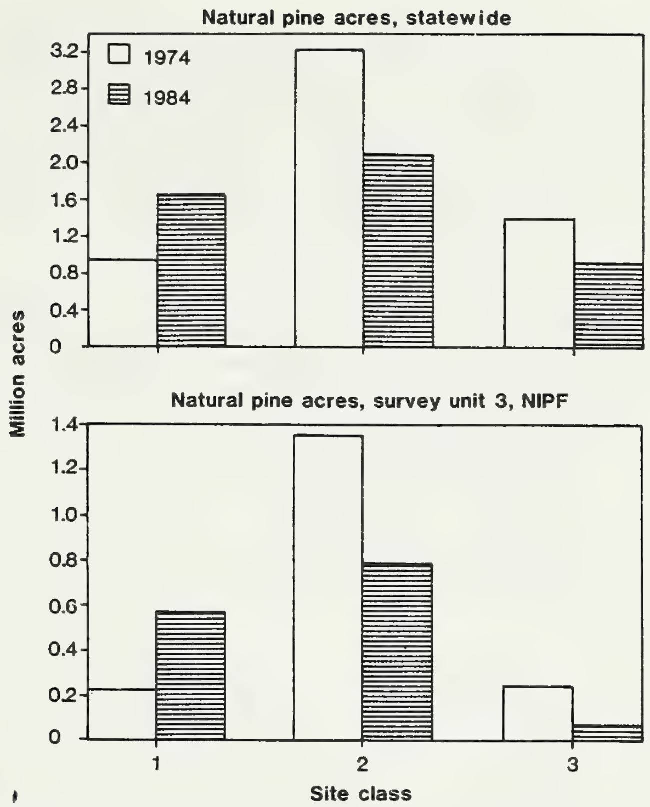

Figure 13—Acreage of natural pine timberland aggregated in three site classes (from the 1974 and 1984 FIA measurements).

The inputs were developed to simulate the shift of acres among three site classes; the site class 1 acres were moved into the inventory from the donor category, and the site class 2 and 3 acres were moved out of the timber base and into the donor category. Inventory volume declined based on the volume per acre associated with the acres removed from each age class of the inventory. Incoming acres contributed to the inventory volume based on the corresponding yield table volume and regeneration stocking ratio assigned stocking level 2 (once volume was assigned, all acres were shifted to stocking level 1 and were averaged into the inventory there). The volume on acres entering site class 1 was assumed to border between site classes 1 and 2. The stocking ratio assigned to entering acres, therefore, was calculated with acres in site classes 1 and 2 and the site class 1 yield table.

Under the average site projection scheme, acres were simply moved out of the aggregate inventory to the donor reserve. Harvest of the acres removed from the natural pine type was simulated by calibrating total harvest to exclude the net volume "lost" to the donor category.

Another for method calibrating the harvest captured volume from the acres shifted into the unstocked category (to represent removal from the natural pine acreage base). As acres were removed from the inventory and placed in the unstocked category, the volume on those acres was used to partially satisfy the requested harvest. This was thought to be a realistic representation of what was occurring in the field. This method could not be used to represent shifting of acres among site classes because too few acres were harvested from site classes 2 and 3 to equal the total acreage loss from natural pine (and site class 1 gained acres).

Projection results did not indicate that one method of shifting of acres was better than another. If the measured acreage shift between site classes did represent a gain in stocking because of an increase in site productivity, then carrying three sites might allow for a more realistic representation of what occurred. Under the average site projection scheme, however, a stocking improvement could be simulated by adjusting the regeneration stocking ratio, the yield table, or the approach-to-normal function, or all three, which might achieve the same effect with less effort.

Harvesting

More than half the statewide 1974-84 natural pine harvest came from acres no longer classified as natural pine in 1984. Acres changed type after harvest through cutting and planting or partial cutting followed by a transition to hardwood types.

Net harvest volume was derived from the 1984 plots that were recorded as natural pine in 1974. Harvest volumes were aggregated by age class (1974 stand age) and converted to 5-year totals. The model accepts a total harvest volume rather than a harvest by age class; it does, however, allow the total harvest to be proportioned across several age classes. So the proportion of the total harvest in each age class was calculated and used in extracting harvest by age class. No cutting was allowed in the first two TRIM age classes (age 0 through 12).

Harvest cannot be specified by management unit. The total harvest is proportioned to the management units based on the total volume available for harvest in each management unit. When three sites were represented with three management units, the total volume harvested from each site class did not necessarily match the measured values.

Note that all the harvested acres in the simulations represented final harvest with no thinning. Thus, all the acres that were cut either returned to the first age class for regeneration or were moved out of the natural pine acreage.

Based on Sheffield and Knight (1986), 28 percent of the acres disturbed for harvest between 1974 and 1984 were partially cut (commercial thinning, selective cutting, or high grading). Thinning was not incorporated into the simulations because the FIA data indicated that only 8 percent of the total harvest volume came from partial cutting, and accurately modeling this thinning would have been difficult.

Two facts were considered when the statewide reduced harvest was derived. The first was the sampling error surrounding the field-measured harvest. This error determines the upper and lower boundaries of the confidence region, and I assumed that adjusting the harvest within this range would not significantly bias the results.

Second, the statewide growth-drain identity calculated with natural pine data underestimated the measured 1984 inventory by almost 9 percent.

The growth-drain calculation for the 1984 inventory was the 1974 inventory minus 1974-84 harvest plus 1974-84 growth. Part of the imbalance at the State level was caused by the way growth was calculated from the data set. Growth calculated from the data set was lower than growth reported by Sheffield and Knight (1986) because it was not adjusted to include growth on plots that were in the natural pine type in 1974 but no longer considered natural pine in 1984. The total plot growth calculated to include all species types statewide did match Sheffield and Knight's (1986).

Because TRIM works with a strict growth-drain principle, "missing" growth cannot be modeled. The compatibility between projections and measurements was improved by reducing the statewide harvest level so the growth-drain calculation would balance. From this point, statewide harvest was further reduced by the sampling error. The total reduction was 25.3 percent (or 861 million cubic feet over 10 years). For survey unit 3 projections, the growth-drain relation balanced within 1 percent of the measured 1984 inventory, so harvest was reduced by only the sampling error.

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Mills, John R. 1989. TRIM timber projections: an evaluation based on forest inventory measurements. Res. Pap. PNW-RP-408. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

Two consecutive timberland inventories collected from permanent plots in the natural pine type in North Carolina were used to evaluate the timber resource inventory model (TRIM). This study compares model predictions with field measurements and examines the effect of inventory data aggregation on the accuracy of projections. Projections were repeated for two geographic areas with two data aggregation schemes. The sensitivity of the model to harvest was tested with historical and adjusted values. For each simulation, the TRIM growth projection mechanism was tested with two types of yield tables. Yield tables developed from growth data produced projections that were closer to the measured inventory than did yield tables derived from volume data. This study suggests that timber growth measurements should be incorporated into TRIM yield tables when stands have the characteristics found in natural pine in North Carolina. The TRIM system is outlined, and the methods used to derive yield tables are discussed.

Keywords: Yield-table projection, growth simulation, growth measurements, inventory data aggregation, inventory models, forest survey, regional timber supply studies, model validation, South.

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